Chapter 4

NASA'S MERBOARD

An Interactive Collaborative Workspace Platform

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Abstract: This chapter describes the ongoing process by which a multidisciplinary group at NASA's Ames Research Center is designing and implementing a large interactive work surface called the MERBoard Collaborative Workspace. A MERBoard system involves several distributed, large, touch-enabled, plasma display systems with custom MERBoard software. A centralized server and database back the system. We are continually tuning MERBoard to support over two hundred scientists and engineers during the surface operations of the Mars Exploration Rover Missions. These scientists and engineers come from various disciplines and are working both in small and large groups over a span of space and time. We describe the multidisciplinary, human-centered process by which this MERBoard system is being designed, the usage patterns and social interactions that we have observed, and issues we are currently facing.

Keywords: Pervasive computing, ubiquitous computing, human-centered computing, collaboration, computer supported cooperative work, user-interface, common information space

1. INTRODUCTION

In 2003, NASA will send two robot rovers to explore the surface of Mars. Dubbed Mars Exploration Rovers (MER), they will operate as mobile science platforms and be the most capable systems ever sent to explore the surface of the Red Planet. With a planned mission lifetime of 90 days per rover, every day on the Martian surface represents a significant amount of time to gather important science data.

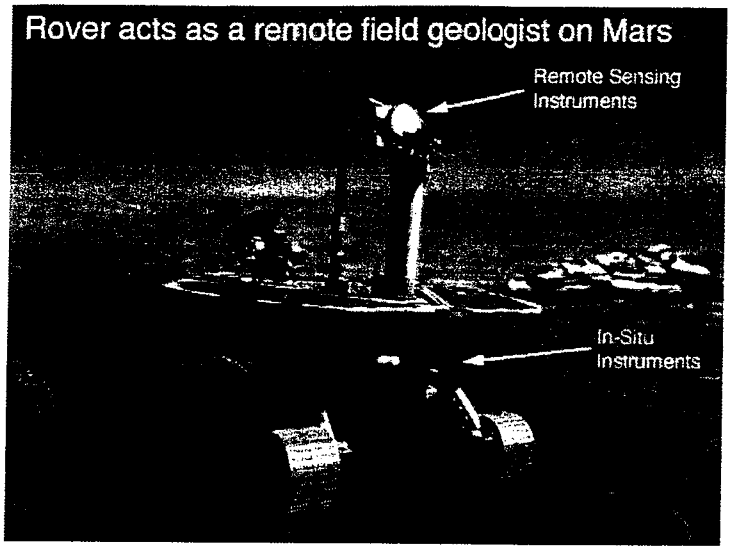

Figure 4-1. [Mars Exploration Rover has remote sensing instruments, and in-situ instruments]

To maximize the productivity of the MER Rovers, the Mission Operations Team at the Jet Propulsion Laboratory (JPL) will communicate with the rovers every day. The science and engineering teams will receive data from the rovers, analyze the data, determine a strategy for operations for the next day, and develop daily command sequences. These command sequences will then be sent to the rovers for execution.

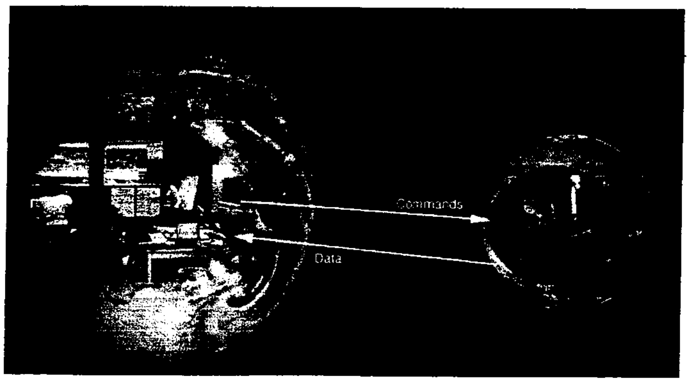

Figure 4-2. [Scientists and engineers on Earth communicate daily with the rover on Mars]

As part of a collaborative effort with JPL, NASA's Ames Research Center initiated the Mars Exploration Rover (MER) Human Centered Computing (HCC) Project in the fall of 2000. Since that time, our team of cross disciplinary (computer science, anthropology, cognitive psychology) researchers has worked with MER science and operations team members applying ethnographic and human-computer interaction research methods and offering recommendations for the design of work processes, procedures and technology to help mission participants accomplish their work. Our goal is to help increase the science productivity of rover surface operations and the effectiveness of communication interactions and collaboration. The MERBoard, a new collaborative, situated, large screen technology for creating, accessing, displaying, annotating, sharing, distributing and saving information within the MER mission environment, is the principal technical innovation to come from this HCC effort.

The MERBoard platform consists of a collection of large, interactive displays, networked together to share information. The displays will be situated on three floors of the Mission Support Area (MSA) at JPL. The MER HCC team developed custom software for this platform so that it will support users as they (a) create, save, retrieve and share information, (b) collaborate within small groups working around a single board, (c) participate in the collaborative work of large group interactions, as well as (d) share information between personal computers and the large displays.

Figure 4-3. [The MERBoard's large touchscreen display creates an immersive environment for collaboration. The software is designed to support tasks in the target domain]

This chapter describes the domain in which the MERBoard will be used. We demonstrate how the research process led to the development of the first MERBoard design requirements and comment on how we believe the board's development will come to provide a specialized "common information space" (Bannon 2000) (Bannon & Bødker 1997) (Bannon & Schmidt 1989) (Schmidt & Bannon 1992) within the mission. We describe the functionalities of the MERBoard and its iterative development process as it has been used by the Mars Rover mission team during training events. We then consider the potential use of these displays as new computing platforms, not desktops, but interactive platforms that support collaboration and can become ubiquitous computing platforms.

2. TYPES OF COLLABORATION THAT MERBOARD MUST SUPPORT

For our team, the human-centered computing process involves understanding a domain by using a variety of ethnographic methods that include in-situ observations of the domain and working in partnership with domain members to determine information, communication and collaboration requirements. This section first describes the collaborative work processes that have been designed by the MER mission system and science team's for their own use during the MER mission, in anticipation of their daily work of receiving rover data, analyzing it, devising a strategy for doing tele-robotic science and developing plans to carry out that strategy by sending commands to the rover. Then we describe some of our ethnographic findings from the early phases of MER mission design, especially in early test and training events, and we show the role that research played in developing the early design requirements for a new technology, the MERBoard.

2.1 The Mission Operations Team

The combined science and engineering team that will operate the rovers on Mars is called the Mission Operations Team. This team is composed of many sub-groups, such as the science team, the science operations support team, the spacecraft team, the mission planning team, the sequencing team, and others. All of these teams must work together to plan and conduct safe and productive rover operations. Since the focus of our work to date has been the science team, here we describe the science team structure for collaboration in the daily planning process. The Science team has been the major focus of our research, with a special interest in the structure of their work process and the need for collaboration in the daily planning process.

2.2 The Science Team

The MER science team will use the rover and its instruments to carry out the missions' primary science objectives

> Determine the aqueous, climatic, and geologic history of a site on Mars where conditions may have been favorable to the preservation of evidence of pre-biotic or biotic processes

During the mission, science team members will formulate and test scientific hypotheses by first analyzing data they have requested from the rover on Mars and then developing new observations and activities for the rover to perform on the current sol. The science team is organized into smaller theme groups according to science discipline. Each theme group has members who work together to set goals and objectives for their discipline. Then a subset of the science theme group members meet together with engineers and other mission personnel in the Science Operations Working Group (SOWG), to develop an integrated set of objectives, observations and rover activity plans. The integrated science activity plan represents the overall goals of the SOWG. Developing these small and large group plans requires extensive communication and collaboration, both within and across the smaller theme groups and within the SOWG. The whole process must be completed each day within a few hours. Successful completion of this process requires access to both current and past information regarding mission decisions and any supporting rationale.

2.3 Small Group Collaboration: Science Theme Groups

The science team is organized into five theme groups: geology, geochemistry, soil, atmosphere and long-term planning. The first four are organized according to discipline, but the fifth theme group, long-term planning, has the job of analyzing the science process and rover operations from a strategic (longer term), scientific perspective. This group will keep track of the science decision process and aid in planning for longer-range activities that could cover periods of a few days to weeks or even months.

The science team works in facilities designed to support collaboration in the decision making process. When science data is received from the rovers each day, individual instrument specialists and scientists will view the data and look for information and insights. Those scientists will then come together in a large Science Assessment Room in the Mission Support Area (MSA), specifically designed to support small group collaboration as well as collaboration across the five theme groups. In this room, there are five separate group areas, each with conference tables and good views of a large overhead projection screens that will project information relevant to each theme group's discussions.

The work of the theme groups will be to analyze and discuss the data and relate it to that team's current thinking as well as to any developing hypotheses. Then they will create a theme group activity plan consisting of a set of prioritized observations they would like the rover to make on the next sol (a sol is a Martian day). In addition to the collaboration within theme groups, group members will circulate within the room, sharing plans and strategies with other theme groups as they attempt to do some early coordination of their planning.

Figure 4-4. [scientists working in a theme group]

2.4 Large Group Collaboration: The Science Operations Working Group

The goal of the Science Operations Working Group (SOWG) is to produce requests for an integrated set of observations and activities that represents the science team's priorities for rover activities for the next day. Examples of activities include the gathering of data using a specific instrument and rover drives that take the rover to new areas and features of interest. The science teams' requested plan is turned into commands and sent to the rover by the rover sequence team.

The SOWG meets after the science theme groups have developed their plans and priorities. Here the collaborative process will continue, but it takes on a decidedly different character. The SOWG group will have approximately forty members who can be active participants and another forty who are expected to be observers. To facilitate this large group collaboration, scientists will move to another room in the MSA that again has been specifically designed to support this type of collaboration. The work will be to develop an overall integrated science plan, deciding on which observations, if any, from the plans of individual theme groups will be incorporated. They will make this decision based on a discussion of the scientific rationale, objectives for the next sol's operations, the overall strategic plan, and the need to meet the planning and engineering constraints set by current rover configuration and available rover resources, such as power and the bandwidth dedicated to data downlink.

During this meeting all of the theme groups present their requests and priorities and develop together a single integrated science plan of associated rover instrument activities and movements that is acceptable to all theme groups and achieves agreed upon scientific objectives. In this meeting, the scientists also work with members of the engineering teams to begin the coordination of science plans and rover engineering plans that are being developed in tandem. This meeting is lead by a single person, the SOWG Chair, who is responsible for delivering a time-ordered list of requested science activities to an integrated team, that will then incorporate science and rover health and engineering plans into an integrated activity plan, do resource planning, turn the plans into commands, validate them and uplink them to the rover on Mars.

3. OBSERVING THE WORK PRACTICE DOMAIN

Our design philosophy calls for observation of existing work practice before proposing technology additions. In many domains we could simply observe existing work practice. This isn't possible for Mars Rover Surface operations, as the landing doesn't take place until 2004. We have been able to observe two rover field tests (Spring 2001 and Summer 2002), and two associated "Mars Yard" tests. It should be noted that the field tests are only partial representations of the real mission, as the timelines, work process and environments are approximations of real mission events and many of the tools and procedures that will be available for the mission, are still being designed. They are however, a valuable opportunity for gathering data by

observing users practicing mission processes. The primary goal of the field tests is to train the science team in tele-robotic operations. For the MER HCC team, the 2001 field tests were a primary source of data used to drive the early MERBoard design requirements. At the 2002 field tests we deployed two MERBoards and observed how they were used. The following summarizes what we observed at the 2001 field test.

In field tests, the scientist engaged in real, not simulated, exploration. What made the explorations "real" was the use of a real rover, situated in the field, with science goals developed in real time for each test. The data used was real images from the field test rover. No simulated data was used. The science teams goal was to determine the location of a rover, which had been placed in a remote desert terrain, and create hypotheses about the geology and geochemistry of the surrounding area. During the tests, scientists worked together to make decisions about the types of scientific observations they wanted to do and worked with engineers, who were co-located in the same area, to create plans for doing science and commanding the FIDO (Field Integrated Design and Operations) rover to traverse and deploy a variety of instruments. During these tests, the JPL test team also introduced a variety of anomalies to train the scientists to deal with conditions they might encounter during Martian surface operations.

During the field test, we used ethnographic methods to gather data, included observing work practice, taking field notes, doing formal and informal interviews, capturing video and still photos, and doing a subsequent analysis of the gathered data, including interaction analysis [Jordan xxx] of the video.

The analysis revealed a variety of constraints on the science team's collaborative process in those early tests. As scientists received data, analyzed it, and made their decisions, we saw limitations on their ability to communicate and exchange information; that is to view, share, present, save and thus refer to important electronic information and material artifacts in both small and large group settings. A 'common information space' was undeveloped. We define the common information space, expanding on Bannon [2000 p. 1,3], Bannon & Schmidt (1989), Bannon & Bødker (1997) and Schmidt & Bannon (1992)., as a communication and information space within a work system that is electronic but that can be supported by related communication events in co-located situations. It is a shared space where information 'objects' are accessible to all and communication, sharing and interpretation are supported as participants construct common interpretations and a common work purpose.

The benefits that come through location in physical proximity and a shared work environment were not enough to fully support the work that was being done in these early field tests. Even though the teams were working face to face, the pressure of the daily timeline required precise and rapid sharing of information of all kinds, verbal, electronic and hard copies so that the team could make decisions and execute a detailed plan of action. The scientists needed "multiple" and "intense" means of communication (Bossen 2002, p.176) in order to develop the common interpretations (Reddy, Dourish, Pratt 2001) that are important to cooperative work and common information spaces. The fact that the science team shared a common expertise and pre-defined goals contributed significantly to their ability to accomplish those goals (Bossen 2002) and was probably the major reason for their success during these early stages of mission design, when facilities, technology support and procedures were minimal and still in development.

The first tests took place in the single room, among grouped tables, chairs and computer workstations whose configurations went through changes with each successive test based on our feedback and the feedback of others (Norris 2002). This was part of an effort to define the first requirements for the physical space that would eventually contribute to a Mission Support Area. FIG 5.

We observed that the scientists had access to the following tools: personal laptop computers; flip charts; notebooks; print outs of schedules, images, and documentation; a twin-screened computer work station in each group area that was running the science activity planning software, still in its early stages of development; and three overhead projection screens that displayed the science activity planning software of the "uplink lead", whose job was to represent the single, common activity plan the team was building each day, along with demonstrating models of rover activity.

Figure 4-5. [The physical layout for the first FIDO Field Test]

3.1 Identifying Information and Collaboration Needs for a Common Information Space

It was in the FIDO field test environment that we first identified information requirements that, in combination with design inspiration from IBM Almaden Research Center's Blueboard [Russell01], would lead to the development of the MERBoard, a technology that we believe will contribute greatly to enhancing communication and developing a common information space during MER surface operations. We began by identifying several areas that needed support: (1) information display, distribution and sharing, (2) a way to generate real time collaborative information representations (3) a way to annotate shared information (4) the ability to save or archive collaborative information generated during the tests and (5) remote viewing and control from one MERBoard to another and from a MERBoard to a personal computer.

3.2 Information Sharing and Display

The need for shared information displays became increasingly obvious over time, as members hung information and images on walls (Fig 6), draped images over flip chart stands, laid out large format images on their work tables (FIG 7), hung information created on flip charts in permanent display situations and used flip charts as a primary means of developing strategic rover plans and presenting them to the team. They also shared information with others simply by "calling out" information about mission updates, meeting times, and science and rover status and updates to the group as a whole. This practice left no information trail and created problems in the test when people who were not in the room failed to hear important information.

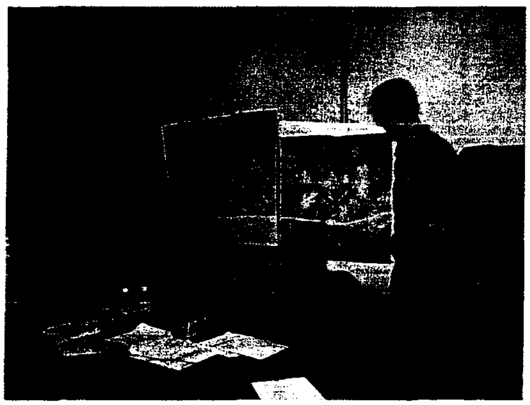

Figure 4-6. [The display and comparison of large format images]

Figure 4-7. [Note how the flip chart pages remain posted as a way of allowing information to continue to be accessible]

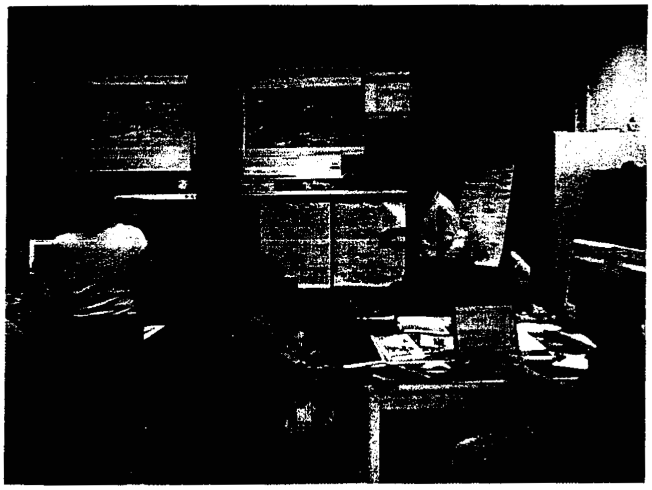

Figure 4-8. [A scientist using flip charts to present during the 2001 FIDO Field Tests]

An influencing factor that contributed greatly to our understanding of how important it would be for members to be able to share and display information was that during these tests there was minimal support for the most standard information sharing venues since copiers and printers were not easily accessible. (Note that the test area is quite different from the Mission Support Area being developed for actual Mars operations.)

Scientists needed to share information in both small and large groups. In small groups, they circulated images and printed information sheets; drew on scratch paper and yellow pads; turned notebooks and laptops for others to see; and pointed to the screen of the activity planning software. In large groups, they used flip charts; held up hard copies of images; used a laser pointer to point to information on the overhead projection screens; or simply verbally referred to their findings without the support of shared visualizations. Perhaps the most compelling instance of attempted information sharing from a requirements perspective was when scientists, who often had supporting scientific information on their laptops which they wished to share, held up the laptop for display to the group in an attempt to show the information to their colleagues.

3.3 Creating Real-Time Representations While Doing Collaborative Work

During the field tests, we saw a progression that began with the use of flip charts early in the planning process. The flip charts allow for free-form expression and were used for brainstorming, hypothesis creation and strategies for verification, as well as flow charts for long term planning (the team called these flow charts Sol Trees). For highly structured activities, such as the creation of rover timelines of activities and command sequences, a specialized mission tool was used.

While flip charts support natural, rapid, handwritten representations, they do not allow for the embedding of related information such as images. They are difficult to store, retrieve and search over long periods of time, and they are not easily shared beyond team members who are co-located and in close viewing range.

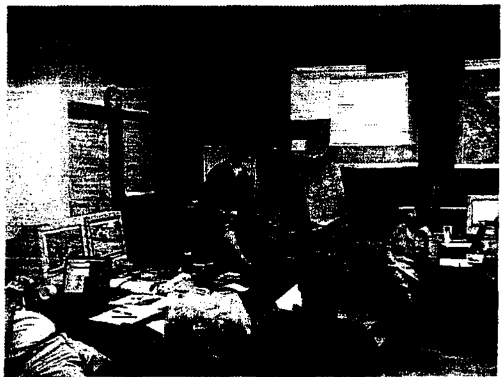

Figure 4-9. [The science team brainstorms on flipcharts and hangs the pages for display]

3.4 Annotating Information

While we saw scientists mark up notebooks and augment information in their computers, we saw only a few instances where people annotated the large hard copy images that were available. Informal interviews revealed that they were reluctant to mar the single copy of an image and yet they were consistently pointing to information, indicating that there was something of interest in it.

4. DEFINING THE MERBOARD

The MERBoard design is intended to assist the mission operations process by addressing the user needs that we observed in the tests, and those that we anticipate for the mission. Note that when we proposed the MERBoard, the critical path tools that would be used to build rover activity timelines and commands were already defined by JPL. By inserting the MERBoard into the mix of mission tools we propose to augment the teams planned work practice.

Success will be measured, not only by acceptance and use, but also by providing needed capabilities that were non-existent or improving ones that were inefficient. As a software platform, its success will eventually be measured as well by the number of groups that adopt it as the mechanism for developing and deploying software in similar collaborative environments.

4.1 Functionality

In deriving the first functional requirements for the MERBoard, we were driven by the observations described above, and design inspiration from IBM's Blueboard [Russell01]. As there are many differences in operations between a field test and a real mission, we had to do our best to account for those differences.

The initial MERBoard design specified the following functionality:

Data display, annotation and distribution, storage/retrieve capability for individuals and groups

Ubiquitous access to information anywhere in the MER MSA

Personal and group storage spaces, with mechanisms for getting information into and out of the MERBoard platform (e.g. from and to a laptop)

Remote access and control, from board to board, and personal computer to board

Simple, efficient mechanisms for capturing any data on the screen, and distributing that data using e-mail and personal/group storage spaces

Following initial interactions with users, we added mission specific functionality:

A Sol Tree Tool, this was requested by a science team member. Sol Trees (remember a Sol is a Martian Day) are flow chart representations of rover strategic plans, showing many possible alternatives for rover activities on each Sol. They were done manually on flip charts during the early field tests. We began by adding flowchart-like capabilities to the whiteboard, such as the ability to auto-attach lines between boxes and easily input text. This quickly evolved into a dedicated Sol Tree plug-in tool. The design is based on observed and planned work practice of the long term planning science theme group. Users can build flow charts of plans, then check a path on the plan to see how it affects mission goals. Mission specific features include the ability to track Sol Type (a sol type means what is the rover doing on that day, e.g. driving, approaching or measuring a target).

Throughout the process of proposing the MERBoard to the MER Mission, we emphasized that it would be easy to use, would require minimal training, and would have a level of simplicity comparable to a Palm Pilot. The users are supposed to feel that they are performing tasks, with their focus being the tasks, not the computer interface. Our challenge has been, and continues to be, how to design the collaborative functionality to best help the mission, while keeping the interface simple, and providing extensibility.

4.2 Functional Overview

One of the keys to the success of the MERBoard is the integration of functionality into a collaborative workspace. We find issues, such as log ins and security, that have solutions we take for granted on the personal desktop, require re-design in a situated collaborative workspace.

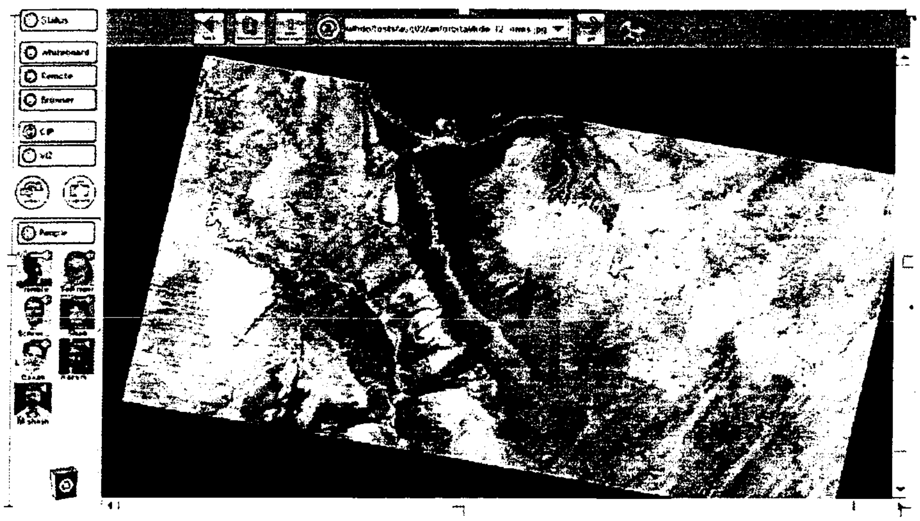

Figure 4-10. [The MERBoard user interface, showing the display of science data using the browser]

Figure 4-10 above, shows the major UI elements. A toolbar on the left side of the screen controls the modes. Functionally, a MERBoard mode is similar to an application. However, we expect that applications on a personal computer go through a startup process and are loaded by the user. For the MERBoard, the user accesses functionality by switching modes, but does not install and startup applications as on a personal computer.

The top three modes, Whiteboard, Remote and Browser, are provided with all boards as these functions are considered fundamental to any collaborative activity. The next two buttons, are reconfigurable and may be specific to a board (the bottom button is user reconfigurable in real time). For example one board might have a data visualization mode for the geology group, whereas another might have a Sol Tree mode for the long term planners.

Below the mode selection buttons are meta-tools. Meta-tools operate across modes and function as global services. Screen capture and e-mail are shown in the figure. The people button opens and displays a directory to access people to display personal information in the collaborative environment (see Ubiquitous access to information, section 4.5).

4.3 Data, Annotation and Distribution

Based on our observations of the use of flip charts at FIDO, and users descriptions of past work practice, such as annotation of surface images during previous missions, we derived the requirement for a whiteboard that has, in addition to basic whiteboard functions, the ability to display, annotate and distribute data. Observed user work practice at FIDO showed, as part of the daily planning processes, science-brainstorming sessions done using flip charts and whiteboards. Most of the work done on the flip charts consisted of unstructured representations, showing early thinking in the formulation of hypotheses and science strategies. Following the brainstorming sessions, the scientists move to structured representations for integrating activity requests into a timeline, from which commands are generated. Critical path mission tools, such as JPL's Science Activity Planner (SAP), support the structured activities, and indeed, impose mission-required structure on the users.

Given that structured activities, of necessity, require users to think in a certain way (note that this structure is not arbitrary it is required for the generation of commands to the rover), it is our supposition that the MERBoard's free-form tools, integrated with data display and annotation, will provide a means to support free-form thinking and representation for scientists and engineers during the mission, without the imposition of structured by the tools. Combined with the large interactive touch-screen, with its immersive qualities, we expect new types of interactions among team members and groups, in the display and analysis of data.

Initial data access and display capability was provided by integrating a Web browser into the board. This allowed access to existing mission data sources. Figure 4-10 shows data displayed using the browser. We also integrated a mission specific tool called Data Navigator, developed by another group at Ames, to provide direct access to the mission database. Other means to display data on the board include uploading data to a personal or group MERSpace (section 4.4) or using remote access to display data from a personal computer or another board (section 4.6).

Any data that can be displayed on the board, in any mode, can be captured using the capture meta-tool, which automatically captures data to the whiteboard. From the whiteboard users can annotate the data, include it in drawings, brainstorms, hypothesis formation and validation, and any other whiteboard activity.

Whiteboards may be saved to a users MERSpace (see section 4.4). To distribute a whiteboard to another user, just save it to their space in any public (non-secure) folder. Each MERSpace has an InBox folder, standard work practice for distribution of files to other users is to put it in their InBox. To distribute files outside of MERSpace, an e-mail meta-tool is provided. The whiteboards native file format is industry standard SVG. This allows editing of exported whiteboards in commercial applications that are SVG compatible.

4.4 MERSpace – Individuals in a Collaborative Space

Collaboration for MER requires access to information at many levels, not only from mission data sources, but personal data. At FIDO, we saw users analyze and create data representations on their personal computers. This data, like the mission data stored in the operational mission database, is part of the data set users require access to. To provide individual users with a means to bring their own data and information into the MERBoard's collaborative workspace, we created the MERSpace, a place for users to store and retrieve their personal data. Rather than thinking of a personal computer, the user has a personal space in a collaborative computing environment. The current MERSpace provides folders, with an explorer type interface, a place for personal bookmarks and automatic one-button access to personal remote computers (see Section 4.6). To minimize complexity, we limited the folders to a single level. Users can create new folders, but not folder hierarchies. Figure 4-11 shows a users MERSpace.

Each MERSpace user has a personal icon. Tapping on the icon selects the MERSpace. The icon also functions as a target, i.e. users can share information by dragging files between their icons. The icon identifies users for remote access requests and e-mail. Users put data into their MERSpace by uploading files from their personal computer using the MERSpace Web Page which provides access to MERSpace over the Web, and provides the user with an interface for uploading files from their personal computer to their MERSpace.

4.5 Ubiquitous Access to Information

MER Mission operations will take place in the MSA (Section 2.3), which occupies three large floors of a building at JPL. It is the Mars Rover equivalent of NASA's Mission Control Center in Houston, seen on TV during Shuttle Missions and the Apollo missions to the Moon. For the FIDO tests, the small physical space provided co-location for collaboration, so access to information across a large physical space was not an issue. This is not true for the mission, with its large MSA.

To address the need for information access across the facility, we provide users and groups with access to their files from any MERBoard, a personal computer running the MERBoard personal client software, and the web. With ubiquitous access, a scientist moving between theme groups need not carry their personal computer with them to discuss their data. An engineer on a tiger team troubleshooting a problem can go from the sequence room to the spacecraft room and have access to the their data.

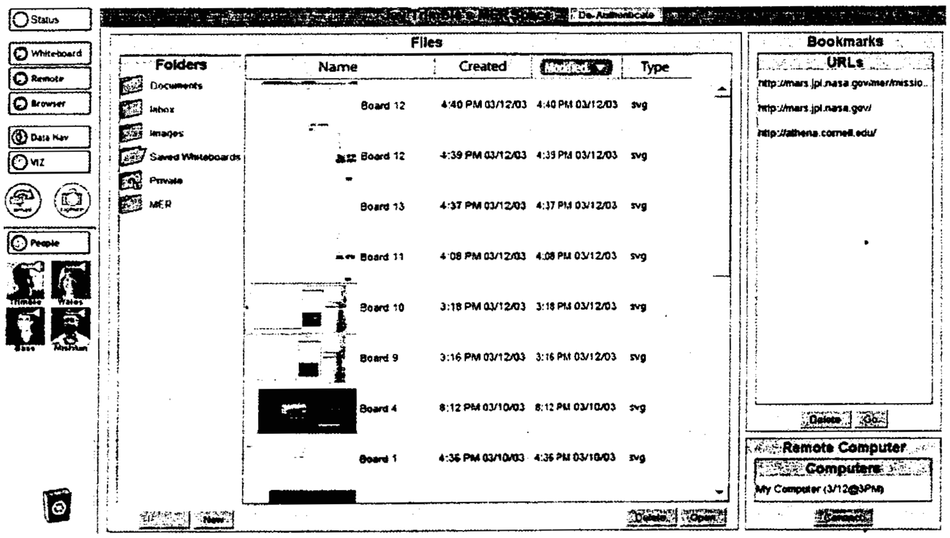

Figure 4-11. [MERSpace, showing the file explorer, personal bookmarks, and remote computer connect]

4.6 Remote Display and Control

Our observations of team members attempting to show data on their personal computers to large groups, and user requests for being able to view and control one board from another, drove the requirement for remote capability. Remote allows one board to display and control another. The same capability works from a board to a personal computer. A user can display and control their PC from a MERBoard. Recall that a users MERSpace (section 4.4) automatically captures the IP address of users who are logged into their MERSpace Web Site. This allows for one button remote access to personal computers. Figure 4-12 shows a personal desktop being displayed on a MERBoard.

Figure 4-12. [MERBoard remote mode, showing a desktop computer on the MERBoard]

4.7 Hardware

The MERBoard hardware is commercial off the shelf (with the exception of the stand which is commercially procured, but custom designed). The display is a plasma unit with a touchscreen overlay. A personal computer runs the MERBoard software, which is written in Java and can run on Linux, Mac OS-X, or Windows 2000.

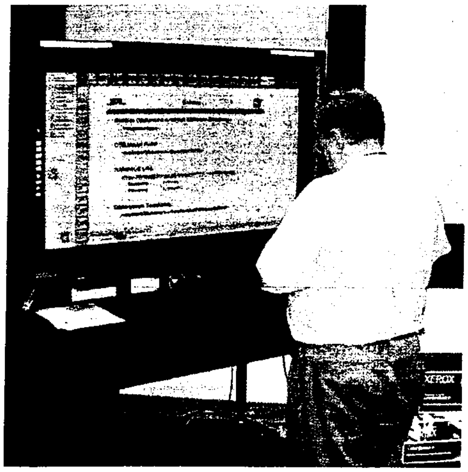

Figure 4-13. [The MERBoard hardware, with a user for scale]

5. ACTUAL USE

We've had two opportunities to observe the MERBoard in use by the MER Mission operations team in training. The first was in July of 2002, at a mission system thread test. The second was at the FIDO field tests in 2002, this was a follow on to the 2001 test, and provided a good opportunity to compare our design assumptions with actual use. Here's a summary of our observations.

5.1 Mission System Thread Test

The mission system thread test was a test of the uplink processes for planning and sending commands to the rover. The users were a mix of scientists and operations engineers. The goal of the test was a successful uplink of commands. This was the first MERBoard deployment at JPL. As the use of the MERBoard in the mission is discretionary, its use was uncertain. There were several factors that affected MERBoard use relative to what we expect in the mission. First, many mission system tools are not yet complete. This proved to be a plus for MERBoard use, as the MERBoard was able to fill in for some of those tools. For this test, many MERBoard features were either incomplete or partially implemented. For example the remote capability was limited for this test.

The board received extensive use for this test. The primary use was display, capture and annotation of target data. Figure 21 shows the actual image used in the test, and the annotations showing target names and direction.

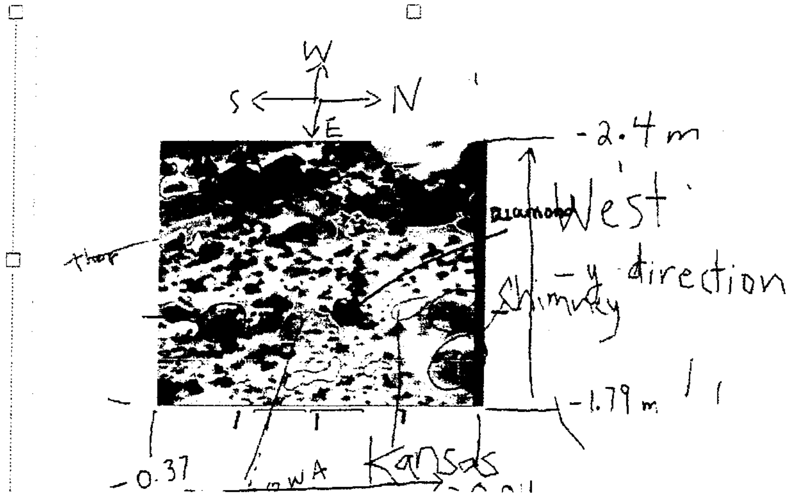

Figure 4-14. [MERBoard annotated image from the mission system thread test]

5.2 FIDO Field Test 2002

In the summer of 2002, we observed the second FIDO field test, placing two MERBoards within the test facility. This test was larger than the first and was held in two rooms instead of one, with a larger number of participants. The test area now more closely simulated the design of the MSA by putting the larger three of the five science theme groups in one room, where they did their analysis and having them move to a larger room next door, where the other two theme groups were located, for the SOWG meeting. The MERBoard collaboration design assumes that each science theme group has their own MERBoard, however, due to the limitations of the facility, we were only allowed to place one MERBoard in each room.

We used a variety of camera setups to capture interactions around the MERBoard and screen capture and logging setups to capture the activity on the board itself. We were able to observe and capture how the board was used, and to compare the actual use to the expected use.

5.2.1 Group Interactions Around the Board

As we had anticipated, the board in the smaller room supported the work practice of the small groups and was initially used to access, and view images and mission relevant information. In fact, groups sometimes grew from shoulder to shoulder collaborators to over the shoulder collaborators as several people gathered at the boards to view images and create representations of interest. The large size of the board facilitated group interactions around images in several ways. First, the size and height of the board allowed people to easily view and interact with images in groups (Figure 4-15).

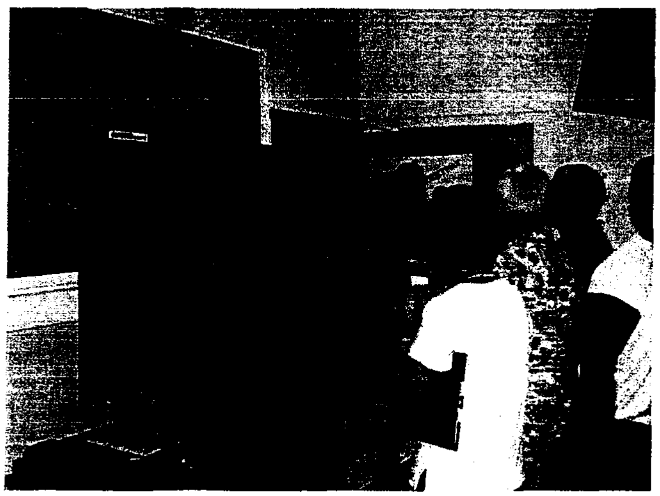

Figure 4-15. [Using the board at the second FIDO Test]

The ability of the board to display large scrollable images, combined with the touchscreen which facilitated interactions, allowed groups of scientists to view large terrains such that all of them could scroll through the terrain, point out features of interest and be active participants in the decision process of selecting features to be designated as targets. Contrast this with the more traditional means of a group of people using a personal computer or workstation to examine large terrain images. In that case several people are crowded around a relatively small screen, usually with one person controlling the computer. The size of the screen, locus of control, and type of interaction is changed significantly in this case. It's also worth noting that large terrain and target images are displayed on the wall during field testing.

While this practice continued even in the presence of the MERBoards, the interaction and use of wall sized images is more constrained and less interactive. Scientists tended to view, rather than interact with, the wall mounted images.

5.2.2 MERBoard as a Pervasive Device and Presentation Tool

With the initial help of some early adopters, scientists used the pervasive set up of the two boards to create and save information in one room and then display it in the second room during the SOWG meeting. Figure 4-16 shows a scientist presenting to the SOWG. Over the period of the tests, the team members adapted their use of the MERBoard during the presentations, using content created on the MERBoards, content created on individual users lap tops and posted to MERSpace, as well as content created on users lap tops then shown and/or captured on the MERBoard using remote mode. Note that the presenter in figure 4-16 can show images to the group, and still be able to directly interact with the image on the screen. This is in contrast to the projection screens where remote interaction using a pointing device is required.

Figure 4-16. [A scientist using the MERBoard to present to the science operations working group]

As we had also anticipated, placement of the boards is crucial to their use. The long term planning group that was located closest to the board in

the smaller science assessment room rapidly became "owners" of that board. Additionally, we had provided some simple tools on the board (boxes and lines) to help this group create Sol Trees, a science process decision tree representation. Over the period of the test, the consistent day-to-day representation of this "tree" on the board formalized both the representation and the use of the board. From time to time, group members who were creating the tree would move to a large white board to make quick notes before inserting them into the decision tree. When the tree was running on one of the screens, other team members appeared reluctant to minimize it and use the board for other purposes.

5.2.3 MERBoard and Traditional Media

Note in figure 4-8 that flip charts were used as a means of developing content and presenting it to the SOWG at the 2001 FIDO Field Tests. The image in figure 4-8 shows a scientist presenting Sol Trees. As previously mentioned, the MERBoard design includes some basic features in the whiteboard specifically designed to facilitate the development of Sol Trees (this has since been extended to a dedicated sol Tree Tool). A key question for the MERBoard team going into FIDO was to what extent team members would use the MERBoard in place of a traditional medium, such as flip charts. Going in to the test we believed that an electronic medium, such as the MERBoard, must have several advantages to have any chance of replacing traditional media that team members were already comfortable using. The advantages that the MERBoard offered for Sol Trees were a large interactive workspace, the ability to easily save, recall and revise drawings, electronic drawing tools, and the ability to develop the Sol Trees on the board in the theme group area then easily bring the same drawing up on the board in the SOWG area for presentations to the group.

Figure 4-15 shows the Long Term Planning Science Theme Group using the MERBoard to develop Sol Trees. Note how the board facilitates group interaction. For Sol Tree development, the users chose MERBoard over flip charts. The use pattern clearly showed that the MERBoards advantages were enough to get the team members to change their work practice and use an electronic medium in place of a traditional one.

6. THE XBOARD AND FUTURE WORK

The MERBoard has evolved into the XBoard, an extensible architecture with an applications programmer interface and a plug-in developers kit. Three developers have started work on plug in applications. The XBoard is a platform for the development of large screen interactive collaborative applications. It is also the foundation for a ubiquitous computing structure for NASA. As part of the XBoard, we have designed a multi-center architecture (MCA). MCA will take the idea of ubiquitous computing beyond the MER Mission Support Area and extend it to conference rooms, design areas and work areas within NASA across NASA centers so that users and groups have access to their data from any XBoard within NASA.

We also plan to develop a personal client. The idea is to have software that runs on a users personal computer to extend the MERBoard/XBoard environment. The client should provide access to the users MERSpace, seamless transfer of data from a personal computer to MERSpace, and easy remote access to the MERBoard/XBoard.

We plan to deploy twelve MERBoards at JPL to support MER surface operations and training. We will observe how they are used and evolve the design based on what we see. No doubt the users will think of many things that we, as designers, have not.

7. CONCLUSION

The availability of large screen displays at affordable costs has created the beginning of a new class of computer. The collaborative interactive computer. The MERBoard, designed for specific tasks in a targeted domain and then deployed in that domain, has begun to accumulate enough use to give valuable data on user reaction to this new class of system. Additionally, based on our initial research, we suggest that this new class of system provides an electronic common information space that helps support collaborative work in intense, co-located situations requiring a variety of information inputs. We believe users will also create new work practices over time that makes maximum use of the MERBoard. Stay tuned for Mars Surface operations in 2004.

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